With the author's compliments.

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DAMAGE BY LATE FROST ON DOUGLAS FIR, SITKA SPRUCE, AND OTHER CONIFERS

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with a note on the occurrence of *Pityogenes bidentatus*, Herbst., on frosted Douglas fir

BY R. N. CHRYSTAL

INTRODUCTION.

ONE of the great difficulties with exotic plants is to know exactly how they will withstand the climate of their adopted country. In Britain it is particularly difficult to judge this, for the climate is a notoriously changeable and treacherous one. The period of greatest danger is, perhaps, the spring when severe late frosts are liable to occur after growth has begun. Forest trees are usually only liable to severe frost damage when of a small size, that is, within the first ten years after planting out. Often the period of greatest danger is over before ten years are passed, and it is usually reckoned that when in any frost area a plantation has grown well above the height to which the cold air lies it is safe from any further serious damage. When thinking in this way, the type of frost damage in mind is that which results in a die-back of the leading shoots of the main stem or lateral branches. It will be seen in the course of this paper that this is not the only way in which serious loss may be caused by frost, and that upon occasion localities which are not usually considered to be bad frost areas can be among those to suffer most severely. The spring of 1927 tested the hardiness of our exotic conifers very greatly, owing to the severe late frost which occurred over the whole country. In Oxford this frost lasted from 27th April to 1st May. The minimum shade and grass temperatures for this period are given in Table 1. The Radcliffe Observatory is situated within the city of Oxford at a similar elevation but in a rather more sheltered position than Kennington nursery, which is just outside the city boundary.

TABLE 1. *Record of Temperatures during Period of Frost*

Date.	*Min. shade temperature at Kennington Nursery.*	*Radcliffe Observatory.*	
		Min. shade.	*Min. grass.*
April 25	44·0° F.	43·8° F.	38·8° F.
„ 26	37·0 „	35·3 „	31·5 „
„ 27	29·0 „	32·9 „	24·7 „
„ 28	31·0 „	33·4 „	27·8 „
„ 29	39·0 „	41·0 „	37·0 „
„ 30	26·0 „	28·0 „	18·5 „
May 1	28·0 „	30·4 „	21·9 „
„ 2	37·0 „	37·4 „	29·3 „
General rise in temperature after 2nd May.			

The forest trees which suffered most seriously were some of the important exotic conifers, including Douglas fir, Sitka spruce, *Thuya plicata*, and Japanese larch. Serious damage was done only in young plantations, and tended to be confined to particular areas. In the nursery some loss also took place, but not to the same extent as in plantations, for nurseries are not usually situated in places liable to serious frosting. Judging by the cases that came under observation, Douglas fir and Sitka spruce suffered greatest damage; and of these by far the worst loss was incurred with the Douglas fir.

Late frosts only affect trees after growth has begun. The cambium, the first tissue in the crown or stem in which growth commences, is the first to be liable to frost damage, and it continues to be susceptible throughout the growing season. After cambial activity has begun the flushing of the new shoots takes place. The tissues of these, both leaf and stem, being in an actively growing condition, are as a whole liable to suffer by frost, and the more or less severe browning and killing of the new growth is the most commonly observed form of damage by late frosts. There are then two ways in which such frosts injuriously affect trees. First the cambium is affected and then the newly developing shoots. The types of frost damage so produced are different and will be discussed separately, the frosting of newly flushed trees being dealt with first.

THE FROSTING OF NEW SHOOTS.

In discussing this phenomenon attention will be confined to those points of interest that have arisen as a result of the April frost in 1927.

Date of Flushing in Relation to Frosting of New Shoots. It is obvious that the date of flushing may have much to do with the amount of damage suffered by the frosting of young shoots. If all trees within one species flushed at approximately the same time it would be a simple matter to decide which particular species had the advantage in so far as lateness of flushing helped it to escape the frosts which usually occur during the spring in Britain. The existence within a single species of races or types differing from each other in date of flushing makes the matter more complicated, but at the same time gives the forester a wider choice when selecting the future crop for any particular area. That types differing in date of flushing exist must be a matter of common observation. It is, perhaps, most easily observed in the horse-chestnut. In Oxford this year the earliest tree noted of this species had its leaves one-third expanded on 6th March, while by the middle of April other specimens were still no further advanced than this. Early and late flushing types are also easily observed in the pedunculate oak, and it has been noted several times (3, 6, and 11) that the late flushing type always tends to escape damage by late frost and is therefore especially suited to some localities. Unfortunately it is also particularly liable to attack by oak mildew and to defoliation (3), and because of this is generally to be avoided. Quite recently attention has been given in Germany (4, 6, and 12) to early and late flushing types of Norway spruce. The early type is held to be the most advantageous, except in mountainous localities above 2,500–4,000 feet and in frost areas. The advantage of

the late type in frost areas can be realized from a statement by Münch (4) that in one locality, as a result of a frost on 8th June 1925, only 12 per cent. of the late flushing type lost their leading shoot, while 90–92 per cent. of the early type suffered in this way.

The existence of early and late flushing types has now been observed in Douglas fir. This is, perhaps, hardly surprising in a tree which within the range of its natural distribution includes so many different forms or varieties. These types occur, however, within one form, the green Douglas fir, and are remarkable in that here again the late type tends to escape loss of new shoots by frosting. They correspond with geographical forms already recognized as the interior dry belt and the coastal type of Douglas fir respectively, and it is found in this country that seed from trees of the former type always flush the earlier and that early flushing is a definite characteristic of them. The reason for the difference in date of flushing is doubtless to be found in the different climates under which they grow in their native country, the coastal type having an oceanic, and the interior dry-belt type a continental and alpine climate. How important this difference in habit may be is brought out by the figures given in Table 2 and obtained from trees grown in Kennington Nursery, Oxford.[1] All the four lots of the interior dry-belt type show a much higher proportion of frosted trees than does the coastal type. Even No. 4 which has suffered least shows a 96 per cent. increase on the coastal type, while in the other cases the proportion frosted is three times as great.

TABLE 2. *Injury sustained in Green Douglas Fir Plots during late Frost, April* 1927

Seed collected from.	*Place of origin.*	*Percentage frosted.*
Interior dry-belt type. No. 1	All British Columbia	79
„ „ No. 2	between lat. 49·0–°	74
„ „ No. 3	50·5° N. and long.	69
„ „ No. 4	117·0°–119·0° W.	38
Coastal type	Western coast of U.S.A.	19

The frost only killed the newly developed shoots, but the result of it was very clearly shown by the autumn in an inferior quality of plant being obtained, in which shoot growth was generally weaker and a multiple top had developed. Although there is a very great difference between the two types in the proportion of trees frosted, it is very doubtful whether there is any real difference in frost hardiness. All that can be said is that owing to the coastal type beginning growth late, it is less liable to suffer from late frosts than a type which begins growth at an earlier date. That both types are equally sensitive to frost, once growth has begun, is suggested by the appearance of frost rings of equal severity in both frosted and unfrosted trees of all the above lots. This simply

[1] This matter was brought to my notice and the counting of the plots done for me by Dr. Steven, Research Officer for England and Wales, Forestry Commission.

means that in all the trees cambial activity had begun at the time of the frost, although on some, and those the trees unfrosted to external appearance, shoot development had not commenced. The results given above show the importance of knowing the habits of different forms of a tree and of using any particular form under those conditions to which it is most suited.

The Effect of Frost on the Shoots of other Species. *Thuya plicata* was very severely affected by the April frost in 1927. In some localities the majority of the trees were entirely blackened and appeared to have suffered very severe injury. The actual damage done was, however, slight, except in frost hollows, where some trees had their leaves rather badly scorched. No opportunity has occurred to observe this species under really bad frost conditions. The general blackening after frost was, however, so remarkable as to be worth recording.

Japanese larch suffered severely owing to the frosting of dwarf shoots. This was especially noticeable owing to the dead frosted leaves hanging on throughout the ensuing summer. Very little permanent damage appears to have been done, and many of the frosted shoots showed great powers of recovery. One phenomenon worthy of note is the development of new buds around the dead growing point. These grow into rosettes of dwarf shoots or form a circle of branches according as circumstances permit. European larch also suffered severely by the frosting of dwarf shoots, and in some cases it seemed that dwarf shoots so frosted in previous years had formed centres for canker development.

THE FROSTING OF THE CAMBIUM.

Its Effects. The effect of frost on the living tissues of a tree depends entirely on its severity. If the cold is sufficiently intense death ensues, but less severe cold merely stimulates the formation of abnormal cells. Thus with regard to the cambium it may be said that two types of damage occur. First it is stimulated to make abnormal growth, and secondly it is killed and a wound formed on the stem or branch affected. As a result of abnormal growth a frost ring (fig. 2) is formed within the wood. Its place in the annual ring indicates the date at which the frost that caused it occurred. Thus a frost ring due to a late frost is found in the spring wood, and any due to frosts occurring later in the year at a corresponding position in the annual ring. Frost rings in the main stem are usually observed in small trees or in the central annual rings of larger ones. They are not usually looked for in the crown of a large tree but may sometimes be found there. Thus material of a frost-injured but still living cambium was collected on 19th May 1926 by Mr. Chalk of the Imperial Forestry Institute at a height of 35 feet up a Douglas fir. In a species the cambium of which is sensitive to frost, frost rings will be formed up to whatever height cold air lies, and in frost hollows the depth of such cold air may be very great. A frost ring usually forms a complete circle, but often only one side of the cambium is affected. Even when a complete ring is formed it can frequently be observed that the cambium has been affected much more

severely on one side than on another. This is most obvious when the cambium is partly killed and a canker develops as a result (figs. 1 and 4). The anatomy of the abnormal frost tissue can be seen from figs. 1 and 2. It is much the same in all species of conifer. Those who wish for a detailed description of it should refer to Rhoads (7) and the literature quoted by him.

The Susceptibility of Different Species. In different species the sensitiveness of the cambium to frost varies considerably. Of the conifers observed Douglas fir seems to be the most sensitive and Sitka spruce follows as a close second. Broad frost rings developed in both Japanese larch and *T. plicata* after the April frost in 1927, but no canker formation was observed. This was particularly striking in one locality where all four species occurred, but only Douglas fir and Sitka spruce developed frost cankers. It would appear, therefore, that Japanese larch and *T. plicata* are the more frost-resistant species. European larch also developed frost rings but to a much slighter extent than Japanese larch. In this respect it appears to be more resistant to frost, but there is some evidence that frost cankers on small European larch branches are much more common than is generally held to be the case; this is being studied further. The only other cankers noticed occurred on pines, in one instance Corsican pine. On two trees, just after the leading shoot had begun to grow, one side of the cambium was killed immediately beneath the leading bud, with the result that a distorted leader developed as illustrated by Rhoads (7) for *Pinus densiflora*. This type of damage appears to be rare and unimportant. In the other case a number of Scots pine transplants that were thriving badly and of a poor colour had developed a frost ring, and in some instances frost cankers, on the main stem. This type of injury is also probably quite unimportant, for the species is noted as being frost-hardy.

Canker on Douglas Fir and Sitka Spruce. Judging by experience during the last twelve months the only species that can be considered as being susceptible to a serious extent to frost damage affecting the cambium are Douglas fir and Sitka spruce. Reports of serious loss in these species have been received from the following counties: Hampshire, Gloucestershire, Somerset, Berkshire, Derbyshire, Norfolk, and Argyllshire.[1] Doubtless a close survey would show that the list could be considerably extended, but it is sufficient to show how widespread this type of frost damage was and how generally it is to be feared. In the case of a small plot of Douglas fir in Marian's Enclosure, High Meadow Wood, Glos., statistics of the loss incurred are being collected. The figures in Table 3 give the information available up to the present time. The rupturing of the bark is a sign of frost canker. It is due to callus overgrowth at the edge of the wound, and is always much more obvious in Douglas fir than in Sitka spruce. According to these figures 63 per cent. of the trees are seriously frosted, and the death-rate in the plantation as a whole is very high, twenty-two trees having died between October 1927 and January 1928. The plot is still under observation and further particulars may be obtained from it. All the dead or missing trees will not have been lost owing to frost, but

[1] Some of this information was received through Mr. J. S. L. Waldie.

many of the trees have been completely girdled and it is to these that the high death-rate is due. In some cases *Armillaria mellea* (Vahl.) Quèl., the honey fungus, has attacked trees, and it is possible that some few of the losses are due to this fungus only.

TABLE 3 [1]

	October 1927.	*January* 1928.
Healthy trees	355	309
Slightly off-colour and showing signs of rupturing of bark, mostly at butt	504	534
Bad colour and bark badly ruptured, mostly at butt	434	428
Dead or missing	201	223
	1,494	1,494

The Position of Cankers and Effect of Girdling. Frost cankers have been observed only on trees up to 10 or 12 feet high. They may occur on the branches or the main stem and at any height up the tree. In general it may be said that, judging by the effect they produce, cankers tend to fall into two classes. First there are those occurring within 2 or 3 feet of the end of the lateral or leading shoots, and second those on the main stem within 6–18 inches or 2 feet of the soil. In both classes the canker frequently girdles the stem. When this happens, in the first class, a die-back of the cankered shoots takes place and, in the second, the whole tree is injured beyond recovery. In both classes a frost ring is usually to be found throughout the tree both above and below the canker. The death of the part of the tree above the place where the branch or stem is girdled does not take place immediately. Usually there is time for at least a few rows of normal tracheids to be formed before this happens, while in trees girdled near to the ground the crown may linger on for a long time before dying. It has not been observed how long the crown of a girdled Douglas fir or Sitka spruce may live in this way, but the crown of trees girdled in the spring may easily be alive, although of a bad colour (as recorded in Table 3), by the following autumn or winter. The crown may keep alive for years in some species, for example, the crown of a Lawson's cypress girdled in 1920 was still living, though of a very bad colour, in 1924. That an affected tree has suffered some damage may, however, be seen during the following summer. By this time fungi will have colonized the dead parts; any leader affected will have died, and trees girdled near the ground become a bad colour. Also, where the stem has been cankered, and especially without girdling, the canker becomes visible, owing to the cracking of the dead covering back by the callus overgrowth. When cankers do not girdle a tree, the part affected recovers unless other factors intervene to cause death.

When may this Type of Damage be expected to Occur? The answer is: At any time when the cambium is active and the temperature sufficiently low. In Britain the spring is the period of greatest danger. Many of the Douglas firs examined were affected before flushing had taken place. There was accordingly

[1] From data collected for me under the instructions of Mr. D. W. Young, M.B.E., Deputy Surveyor Forest of Dean.

at the time the frost occurred no external sign that the tree had been in any way injured by it, and when, later in the year, perhaps the greater part of a plantation turned a bad colour and showed parts of the stems infested with bark fungi, it was often completely overlooked as the primary cause of the disease.

THE TYPE OF LOCALITY IN WHICH DAMAGE OCCURS AND THE RELATION OF SURFACE VEGETATION TO IT.

While some of the cases of this kind of damage were found in frost hollows, none of those which came under notice occurred in localities which are notoriously dangerous from late frosts. None of the localities examined were on steeply sloping ground where good drainage of cold air might be expected, but sometimes they were so situated that no drainage of cold air into them could take place. The localities were, therefore, of two types, first frost hollows of a mild type, and secondly flat areas from which the quick drainage of cold air is impossible. In some cases no previous frost damage had been observed in them, but it is to be noted that the presence of frost rings due to late frost in the annual rings of years previous to 1927 showed that dangerous frosts had occurred before. In no instance examined had these previous frosts been of sufficient severity to cause canker. Thus in a Sitka spruce in 1927 the main stem was badly cankered in several places, although not girdled. In 1926 a severe frost ring developed throughout the main stem and in 1925 a partial frost ring developed. It is of especial interest to note that this partial ring occurred on the side where two years later the cambium was killed. Careful consideration showed that, taking the localities as a whole, the more serious damage was not to be associated with the collection of cold air in any particular area. Frost rings might arise owing to this, and cankers causing the die-back of shoots also appeared to be associated with it, but not the severe cankering with or without girdling of the lower part of the main stem, which has been by far the most serious cause of loss. In every locality examined this type of damage has been associated with a surface vegetation in which grass dominated, with or without rushes, and it is here that the cause of the trouble must be looked for. Wherever a different surface vegetation existed, such as bracken or bramble, the damage was either very much less severe or failed to occur at all.

This correlation between the presence of a ground flora of short thick herbage and the production of frost cankers can be most marked. For example, in a small plot of Sitka spruce in Bagley Wood, Oxford, the trees seriously frosted always stood in small islands of grass in the midst of the bracken and bramble which otherwise constituted the dominant ground flora. The bramble and the dead bracken stems undoubtedly gave protection against frost, while the grass increased the danger from it. Similarly in a Hampshire plantation of Douglas fir the trees that had escaped damage stood in small areas of bracken or bramble, very clearly marked out from the remainder of the plot in which grasses and rush dominated. The small area of Douglas fir from which the data for Table 3 were obtained showed a similar state of things. Here in July it could easily be seen that the trees that had suffered least stood in the midst

of bracken and bramble, as contrasted with a dominant ground flora of grass, for the rest of the plantation.

When the external damage due to frost occurs within a particular zone, it must of necessity be assumed that it is within this zone that the most severe frost occurs. Thus when frost cankers occur generally, as shown in Table 3, on the lower part of the stem it is the air surrounding this part and standing immediately over the ground that was coldest and its low temperature that is the cause of the death of the cambium. The occurrence of this zone of specially cold air is to be explained by the minimum grass temperature. If the figures given in Table 1 for the minimum shade and grass temperatures at Radcliffe Observatory are examined it will be seen that on 27th April the minimum grass temperature was 8·2° F. below the minimum shade temperature, while on 30th April it was 9·5° F. below and reached the minimum temperature for the period, 18·5° F. On higher and more exposed sites than that on which this observatory stands the temperature was probably three or four degrees lower still.

Staudacher (10), confronted with a similar problem in connexion with Norway spruce, also came to the conclusion that the low temperatures occurring over grass were the cause of much severe frost damage. He found that the lowest temperature occurred at the tips of the grass blades. It has not been possible to check this, but the fact that no cankers have occurred nearer than about 6 inches to the surface of the soil suggests that he is right.

The importance of the ground flora can be stressed further by citing another case in Bagley Wood. Here a plantation of Douglas fir stands in a frost hollow. The ground flora is chiefly thick bramble, with a few small birch and willow as weeds, and in some places bracken. It is noticeable that the common type of frost damage is a die-back of the shoots, and that cankers low down on the main stem are rare. Such frost cankers as do occur have been found above the level of the undergrowth and chiefly on branches. Obviously here the thick undergrowth, in so far as it is able to cover the trees, is acting as a protection against frost.

THE RELATION BETWEEN SILVICULTURAL TREATMENT AND FROST DAMAGE.

After the felling of an old crop, is any indication ever given that the conditions of the soil change so as to increase the danger from frost damage? The answer is that in localities where frost cankers are liable to develop such can sometimes undoubtedly be found. The Hampshire Douglas fir plot above mentioned is a case in point. This plot stood at the foot of a slope, the upper part of which was planted with larch. The ground gently sloped away from the Douglas fir, and was covered with oak-high forest such as the conifers had replaced. A small stream ran down the hill-side, and the ground on either side of this, and around the springs from which it arose, was at the time of felling the only definitely wet or marshy soil. For this reason it alone was planted with Sitka spruce. At the time the plot was examined the Douglas fir were 6–9 feet high and up till 1927 had done exceedingly well. The plot as a whole had, however,

largely become invaded by rush, and there was every sign that since replanting the soil had become definitely more wet and less well drained. The felling of the old crop had evidently resulted in a raising of the water-level and an increase of the water content of the soil, and due to this change in water conditions, a change in ground flora was coming about. Bracken was entirely, and bramble chiefly, confined to the better-drained parts of the area where the soil was warmer and drier, and it was in these parts that the frost had done least damage. The interpretation of this is that there are certain sites in which, after clear felling, the soil will definitely become more cold and wet, and on which an unfavourable type of ground flora will develop. This will tend to turn the site into a potential frost area, unless precautions can be taken to prevent such a development. The researches of Burger (1) into the physical condition of the soil lead one to expect that this should be. He found that after clear felling the soil became more compact; its air content decreased, and that in many cases there was a definite increase in water content. None of these developments can usually be considered good for the growth of the new crop, although often they may be so slight as not to cause any noticeable difference to it. But where good drainage of the soil depends on the presence of a standing crop they can be very important, and changes such as those indicated may often be seen. Close observation of a locality will sometimes show where they are to be expected, and then every precaution should be taken to prevent deterioration in soil conditions, and the development of a frost area.

THE PREVENTION OF DAMAGE DUE TO LATE FROST.

Out in the forest die-back or canker due to frost is only likely to occur in particular areas, but within these areas much trouble may be experienced, and considering their size, no inconsiderable loss suffered. Fabricius (2), writing on Sitka spruce in Denmark, remarks on the occurrence and prevention of frost damage. There, spring frosts are apparently of little consequence except on flat areas, such as heaths, or in hollows at a distance from the sea, where the danger may be great. A thick covering of grass is said to increase the danger of frost damage. In substance this agrees with experience in this country and is confirmation of what has been said above. He further states that where there is a danger from frost, an advance crop of birch helps to give protection. In some cases, as on poor heaths, nurses of mountain pine are used for the same purpose. When planting up frost areas in this country it may also be found useful to have nurses, or at least to leave any growth standing that is capable of giving protection against frost. Sometimes it will also be necessary to drain an area in order that the soil and ground flora may be maintained in a favourable condition so far as is possible. Apart from this the only thing to do is to chose a species that is not sensitive to late frosts, and often this will be preferred as being least troublesome and expensive. It is here that late flushing varieties of trees may prove to be a great advantage. What is actually done should be that which will produce the most profitable crop; but the determination of this is a matter for experience and to be decided by those with a knowledge of local conditions.

FUNGI AND FROST DAMAGE.

It is, of course, generally known that frost-injured parts provide one of the most common types of infection centre for parasitic fungi. These fungi are usually facultative parasites, capable of living as saprophytes, and often are only dangerous when their host has been injured, as by frost, or reduced in vigour by some other means and so unable to resist attack. During the summer after a really severe late frost it is common to find parts of young trees dying back. This is apparently due to fungous attack, and only on close examination is it discovered that the primary cause of the trouble has been frost. Unless the possibility of frost damage is borne in mind it is quite easy to consider the fungus as the first cause of disease, and in many cases this has been done. When a die-back occurs from the tips of the shoots downwards, frost is naturally thought of as a possible cause of damage, but when the sole damage is a canker on the main stem this is not so obvious. It has to be remembered that such cankered trees often show no signs of distress until well into the following summer. It is quite possible in some cases for them to live for several years after complete girdling, and yet show no more sign of distress than an abnormal colouring of the leaves. Here then frost is often not suspected, and the dead bark, colonized by a fungus known to be associated with the die-back of trees, may be blamed for the trouble. In the case of the Douglas fir and Sitka spruce examined during the last year, one of two fungi, *Myxosporium abietinum*, Rostrup (8 and 9), and *Phomopsis Pseudotsugae*, Wilson (13), were always found on the frosted parts. They never spread beyond the tissue killed or very severely injured by frost, unless the tree as a whole was so badly affected that it must in any case die back to a very great extent. The trees examined undoubtedly showed that these fungi were not acting as virulent parasites, and that any tree in a reasonably vigorous state could resist them.

Apart from these fungi affecting the bark of the crown, *Armillaria mellea* sometimes occurred, but also only as a secondary parasite, destroying trees already much weakened and in some cases dying. In a European larch it was obvious that frost injury assisted in the spread of this fungus within the host. The fungus had apparently entered the root of the tree during the previous late autumn or winter, for the 1926 annual ring in the root was completely formed. It had, however, only spread up the tree on the side on which frost injury was greatest. Frost had not killed this tree, but only caused the development of a frost ring at the beginning of the spring wood. Abundant traumatic resin ducts had developed, undoubtedly as a result of the fungous attack.

The occurrence of *Pityogenes bidentatus*, Herbst., the two-toothed pine beetle, on frosted Douglas fir

This beetle may provide a further complication to the problem of disease control. It was found working in the stems of young Douglas fir from King's Lynn, Norfolk. The plantation affected was set in a hollow on the top of a hill and surrounded by an older plantation of conifers. It was therefore in

a possible frost area. The tree sent for examination showed very typical frost cankers (fig. 4), and it was in these frosted parts that the beetle began to work. Apparently its attack upon the tree commenced last year, as only one brood tunnel was found (fig. 3), from the neighbourhood of which six adult beetles were recovered, four males and two females, no larvae or pupae being present. The exit holes of several other beetles were observed in the bark and another female was found boring into a green and resinous branch node slightly higher up the stem. The gallery system which covered an area of about 5 inches in a vertical direction completely encircled the stem and showed two well-marked mother galleries, the third being rather indefinite. The beetle in this case is evidently following closely upon the frost and fungus damage, and will probably increase the scope of its attacks during the present season if left unchecked. This type of secondary damage to young coniferous plantations is referred to by Dr. Munro (5) in his bulletin on British bark-beetles. Scots pine and spruce are the most common breeding-hosts of the beetle, but larch, silver fir, *Thuya*, and Douglas fir are also attacked.

SUMMARY.

(1) In this paper is discussed the effect upon certain exotic conifers of the severe late frost that occurred at the end of April 1927, Douglas fir and Sitka spruce being the species chiefly concerned.

(2) It is shown that the frost caused three types of damage: (*a*) it killed the newly developing shoots, (*b*) it killed the cambium, or (*c*) caused the formation of a frost ring.

(3) The effect of frost on newly growing shoots is discussed in relation to Douglas fir. The green form of this tree is shown to have early and late flushing types corresponding to those forms already known as the interior dry belt and the coastal type respectively. Only 19 per cent. of the late type had their shoots cut back as compared with 39–79 per cent. of the early type.

(4) The effect of frost on the cambium resulted in the development of large frost rings in Douglas fir, Sitka spruce, *T. plicata*, and Japanese larch, and sometimes in smaller frost rings in European larch.

(5) Douglas fir and Sitka spruce, but not the other species, also suffered severely owing to frost killing the cambium and thus causing cankers, many of which girdled the stems affected.

(6) The girdling sometimes resulted in a die-back of the leading or lateral shoots, but the most serious loss was caused by cankers girdling the lower part of the main stem and thus entirely ruining the tree.

(7) This type of frost damage does not show at once, and the subsequent dying-back of trees affected is frequently put down to parasitic attack by fungi which colonize the frosted parts. The fungi found on Douglas fir and Sitka spruce have been *Myosporium abietinum*, Rostrup, and *Phomopsis Pseudotsugae*, Wilson. In this case both have been acting as secondary causes of disease, and have shown no signs of being virulent parasites.

(8) Frost-cankered Douglas fir have also been attacked by the two-toothed

pine-beetle, *Pityogenes bidentatus*, Herbst., which also acted as a secondary parasite colonizing the frost cankers in the first place and attacking green parts of girdled trees afterwards.

(9) The cause of the cankering of the lower part of the main stem is shown to be due to the low temperature of the air lying immediately over a ground flora in which grass dominates. On the other hand, where the dominant surface vegetation is bracken or bramble or of a similar type, protection is given against frost.

(10) Evidence is brought forward to show that in certain localities clear felling may so adversely affect soil conditions as to favour a bad type of surface vegetation and cause the development of an area in which frost canker will occur.

(11) If this type of damage is to be prevented careful attention must be paid to drainage, and if necessary regeneration should be carried out under an advance crop of such a species as birch. If this is not profitable a frost-hardy species must be used.

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EXPLANATION OF PLATE I

Fig. 1. Frost canker of Douglas fir in cross-section, and showing frost ring and traumatic resin ducts. × 4 times.

Fig. 2. Enlargement of frost ring in the same tree. × 30 times.

Fig. 3. Galleries of *Pityogenes bidentatus*, Herbst., in frosted Douglas fir stem. × ½ times.

Fig. 4. Douglas fir stem in cross-section, showing frost canker. In the 1927 (the latest) annual ring is a broad frost ring. At the beginning of the 1926 annual ring is a much slighter frost ring, which is marked by the slightly darker colour. × 1½ times.

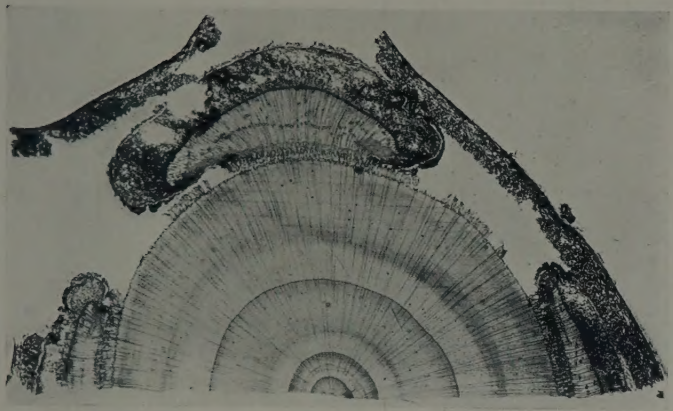

FIG. 1

FIG. 3

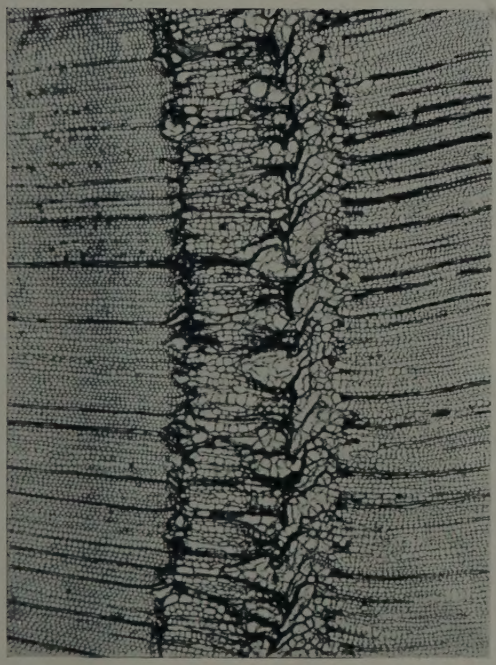

FIG. 2

FIG. 4

PLATE I

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